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UNCERTAINTIES IN THE PREDICTION OF HIGH-ALTITUDE NUCLEAR EFFECTS

Ernest Bauer

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The presentation begins by establishing the relation between the threat, the environment, and the effects on survivability and operability, lists different effects of significance, and then presents a qualitative overview of our present understanding of the atmospheric nuclear environment.

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Finally, a summary on data and models is given.

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This document summarizes the uncertainties of some of those predictions of High-Altitude Nuclear Environments which users of the information--in particular system architects and element designers--need. These users may accept the results of the detailed MICE/MELT, NORSE, or SCENARIO codes too uncritically, mistaking precision for accuracy. Note that the significance of a given uncertainty depends on the specific use, i.e., one cannot give useful, generic and yet numerical uncertainty estimates. The reader with specific questions is urged to contact the Defense Nuclear Agency (DNA) or their contractors.

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CHART 1. CONTENTS

CHART 2. THE CONTEXT: ENVIRONMENT AS COUPLING BETWEEN THREAT AND USERS (System Architects and Designers)

THREAT	<=>	ENVIRONMENT	<=>	USERS
SALVAGE FUZING		X-RAY FLUENCE		SURVIVABILITY
PRECURSORS		GAMMA-RAY FLUENCE		
RADAR/ IR FENCE		ELECTRON DENSITY AND VARIANCE		OPERABILITY RADAR, COMMUNICATION
LADDER UP/ DOWN		OPTICAL RADIANCE (IR, VIS, UV)		OPTICAL SENSORS

Chart 2 sets the nuclear environment in context, as coupling between the designated *threat*--how nuclear weapons might be used in practice--and what concerns *users*, which is element or system *survivability* or *operability*.

The nuclear-perturbed environment, which determines survivability and operability, consists of fluence or flux of X-rays, gammas, neutrons, etc., which determine the required system element hardness and the background in which radar, communication systems, and optical sensors have to operate. This is, respectively, electron density and its small-scale variability (which affects the RF signal scintillation) and optical radiance and its small time-space variability which determines the target detectability through "clutter."

This environment, in turn, is determined by where and when nuclear weapons are detonated, which is a function of tactics:

- "Salvage fusing" denotes weapons fused to go off when an interceptor hits them.
- "Precursors" are weapons detonated early or late and designed to produce interference with one or more of the surveillance or interceptor functions.
- "ASAT"--means anti-satellite; "PINS = point-in-space nuclear ASAT; "DANASAT" means "direct ascent nuclear ASAT."
- A "fence" is a series of detonations spaced to confuse IR or radar sensors.
- "Ladder-up" means warheads detonated to go off at successively higher altitudes and later times to screen rising ICBMs, while in "Ladder-down" the detonations walk down to screen the entering ICBMs.

Conceptually we have a flow of *environmental needs* from right to left and of *environmental data* from left to right. We address this structure in terms of its gaps.

CHART 3. WHAT USERS NEED TO KNOW ABOUT THE NUCLEAR ENVIRONMENT

- DIFFERENT USERS HAVE DIFFERENT NEEDS, GENERALLY EXPRESSED IN TERMS OF AN EXPECTED (OR MOST LIKELY) VALUE OF A CRITICAL PARAMETER AND ITS ACCOMPANYING VARIABILITY.
- RELATION OF THREAT TO ENVIRONMENT FOR SPECIFIC EFFECTS (SURVIVABILITY AND OPERABILITY)
- A FEELING FOR THE RANGES OF UNCERTAINTIES IN PREDICTIONS, AND WHAT DRIVES THE UNCERTAINTIES
- A FEELING FOR SATURATION EFFECTS IN PREDICTION OF NEUTRAL AND ELECTRON DENSITY, OPTICAL RADIANCE, ETC.
- ULTRAFAST NUCLEAR MODELS FOR COMPLEX MULTI-VEHICLE ENGAGEMENT CODES

Chart 3 enlarges on the context of this work, supplementing Chart 2.

The designer or architect needs to have a feeling for the ranges of uncertainties of the various parameters that affect his system. This is very important, but hard to make quantitative. One example is provided by RF communication. Suppose we can transmit through electron densities $n_e = 3 \times 10^9$ el./cm^3, and predictions are reliable to within a factor of 3. Then regions showing $n_e < 10^9$ permit propagation,[1] while regions with $n_e > 10^9$ have to be avoided to enhance the probability of communication link operability. One way to achieve this is by link diversity.

This example indicates that we need to have a feeling for the *ranges of uncertainties* of predictions. The X-ray fluence due to an MT-range burst is probably known to within $\pm$ 20%, while the induced electron density n_e is known to within a factor 3 or 10. The fluctuations (scintillations, clutter) may have significantly larger uncertainties, and may determine the system design.

The relation of Threat to Environment is discussed in Chart 2.

In a multiburst environment there are also *saturation effects*, so that, at times greater than a few seconds after a burst, the electron density n_e is generally less than 10^{11} el./cm^3 as a result of the balance between burst energy deposition and collisional-radiative recombination. Charts 12 and 13 indicate possible enhancements in high-altitude neutral and electron density following nuclear detonations.

Finally, for engagement codes used for system simulation which have to follow the motion of a very large number of different space vehicles we are severely constrained by total computer run time, i.e., we need ultrafast descriptions of the nuclear environment, if necessary at a sacrifice in precision.[2]

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1 Because a prediction $n_e = 10^9$ means that the actual ionization will be $< 3 \times 10^9$.

2 The reason for writing "precision" rather than "accuracy" is that the possibility of unanticipated physical effects cannot be excluded, because of the very limited number of high-altitude nuclear tests.

CHART 4. DIFFERENT NUCLEAR ENVIRONMENTS

	PROMPT (SEC)	PERSISTENT (MIN-HOURS)
ENDOATMOSPHERIC	• Dynamic Overpressure • Thermal • (EMP) • (Ground Motion)	• Dust • Fallout • Electron Density • IR Irradiance
EXOATMOSPHERIC	• X-ray Fluence • Gamma Dose Rate • Prompt Betas • Prompt Gammas • Neutron Fluence • KE and Beta Patch • EMP	• IR Irradiance -- Plasma -- Molecular • Electron Density • Debris Gammas • Debris Betas • Trapped Electrons • Neutron-Decay Betas

In the nuclear-disturbed atmosphere there can be major changes from the ambient atmosphere. Within the atmosphere ("Endoatmospheric Regime") there is a fireball, and thermal radiation and, in particular, shock waves in both the air and sometimes in the ground, as well as other effects such as ground motion, dust, and fallout.

At altitudes above 70-100 km the ambient atmospheric density is so low that not all incident X-rays, gammas, neutrons, etc., are absorbed, giving rise to different effects. This is the "Exoatmospheric Regime." There are so few actual nuclear test cases above 90 km that the uncertainties are most significant here, and this is the region which is discussed in the present document.

Appendix A expands on Chart 4 by pointing out that nuclear effects can be characterized in a variety of different ways: by time (prompt--typically less than 1 sec--where survivability issues are critical, and persistent where operability issues dominate), by phenomenology, by statistics, and by type (blast, radiation, thermal, ground motion, IR, RF, etc.).

CHART 5. LEVELS OF UNDERSTANDING OF NUCLEAR ENVIRONMENT--HIGHLY SCHEMATIC

KNOWLEDGE	APPLICATION		EFFECTS OF UNCERTAINTY
GOOD	SURVIVABILITY:	X-RAY HARDNESS	SMALL
		β & γ HARDNESS	SMALL
FAIR/ MODERATE	COMM:	IONIZATION	MODERATE
		STRUCTURE	CAN BE LARGE
MODERATE/ POOR	SENSOR OPERATION:		
		RADAR	SEE COMM
		IR	MOD/LARGE?
		UV/VIS	LARGE?
		STRUCTURE	CAN BE LARGE
POOR/ZERO	(WE COULD BE MISSING SOME PHYSICS BECAUSE THERE ARE NO MULTIBURST HIGH-ALTITUDE DATA)		

Chart 5 attempts to indicate our level of understanding of different kinds of environments. It is difficult or impossible to do this in a quantitative, generic, and yet meaningful way because the significance of a specific quantitative uncertainty depends on the application and on the particular user.

It ranges from those cases, such as X-ray and beta or gamma hardness which are well understood because there are a great deal of data (here from simulations and underground tests) to those cases such as IR backgrounds and its fluctuations ("clutter") where there is little or no nuclear test data.

Regarding phenomenology, ionization, and optical radiance, frequently our understanding for bursts below 100-150 km is significantly better than that at higher altitudes, in particular above 500-600 km where there are no nuclear test data.

The final column on this chart ask for the effects of the uncertainty on systems applications, but once again the effects of an uncertainty depend critically on the specific application.

Note that here we only speak about exoatmospheric effects: there are sufficient low altitude nuclear test data that uncertainties will be much less significant in the endoatmospheric regime.

CHART 6. DATA BASE

ATMOSPHERIC BURSTS:

- LOW ALTITUDE: MANY BURSTS BEFORE 1962
- INTERMEDIATE ALTITUDE (30-90 km) : DATA ON 3 BURSTS BETWEEN 1958 AND 1962
- HIGH ALTITUDE (> 90 km): DATA ON 3 BURSTS IN 1962 (PLUS VERY LIMITED DATA FROM THE 1958 ARGUS SHOTS)

UNDERGROUND TESTS:

- MANY: PROVIDE VULNERABILITY/SURVIVABILITY/HARDENING INFORMATION

PARTIAL HANE SIMULATIONS:

- BARIUM RELEASES
- EXCEDE, AURORAS, EQUATORIAL SPREAD F, ETC.
- WIDEBAND, HILAT AND POLAR BEAR SATELLITES ACQUIRED DATA ABOUT THE NATURAL ENVIRONMENT
- HEL EXPERIMENT AT NRL, AND LABCEDE, COCHISE, LINUS AT AFGL
- CALCULATIONS VERSUS SIMULATION EXPERIMENTS

Chart 6 summarizes the available data base relevant to nuclear explosions. Because of the Atmospheric Nuclear Test Ban Treaty, there have been no U.S. (or USSR) atmospheric nuclear explosions since 1962. Before this there were many tests at low altitude, ranging from the surface up to 20 km and providing a substantial data base--see, e.g., Glasstone, 1964. There were three U.S. tests in the intermediate altitude region (30-90 km, in 1958 and 1962), and three high-altitude bursts (90-400 km).[3] Analysis of the test results has been continuing since then--see, e.g., Hoerlin, 1976, Reed et al., 1980, and White et al., 1987b.

There have been many underground tests (UGTs), which are continuing, as permitted by the Test Ban Treaties. They provide extensive information on vulnerability and hardness.

Because of the very limited number and instrumentation of high-altitude tests, there have been many attempts at *partial simulation*, some of which are listed here:

- Barium releases. When atomic barium is released in the sunlit ionosphere, it is ionized to a significant extent, and both neutral atoms and atomic ions can be diagnosed by solar optical fluorescence. This enables us to study the motion, structuring, and perhaps decay of these plasma clouds.
- An aurora is the result of atmospheric ionization by keV electrons of solar origin, giving rise to radiation from O, N, O_2, NO, N_2, and their ions. The EXCEDE experiment is a partial simulation in which a small region of the ionosphere is dosed with keV electrons from a rocket-borne electron accelerator.
- The Spread-F campaign studied ionospheric scintillations, and the Wideband, HiLat and Polar Bear satellites provided information relevant to the interaction of a HANE with the ionosphere.
- There is a variety of laboratory experiments in relatively large facilities with cooled walls[4] to study air photochemistry by a variety of microwave, laser, and other modes of excitation.
- Finally, it should be noted that computer codes on High-Altitude Nuclear Explosions (HANEs) are generally verified to the greatest extent possible by these various simulations--see, e.g., Holland et al., 1977, and White et al., 1987b.

---

3 The altitude of intermediate and high-altitude bursts is shown in Chart 12. Note that there were also the high-altitude Argus tests, but the instrumentation was so limited that little or no usable data is available from them.

4 Both large size and also cooled walls reduce the importance of surface reactions.

CHART 7. WHAT WE DON'T HAVE

- MULTIBURST EXPERIMENTAL DATA

- QUANTITATIVE EXPERIMENTAL EVIDENCE ON HEAVE:
  - CRITICAL FOR MULTIBURST PHENOMENOLOGY
  - SOME QUALITATIVE INFORMATION FROM 3 HIGH-ALTITUDE BURSTS OF 1962
  - THE DNA COMMUNITY IS MORE SANGUINE ABOUT OUR UNDERSTANDING IN THIS AREA THAN I AM

- RF DATA ABOVE UHF (THERE ARE RADAR DATA TO X-BAND)

- GOOD OPTICAL DATA ABOVE 0.68 μm:
  - PREPONDERANCE IN 0.38-0.68 μm RANGE
  - NO IR DATA ABOVE 5.5 μm
  - NO UV DATA (BUT STRONG INFERENCES FROM ONE 1962 HIGH-ALTITUDE TEST)

- ADEQUATE ANALYSIS OF UV EFFECTS

- STRUCTURE--VERY LIMITED DATA

Many required data on HANEs are not available, both explicit multiburst effects such as "Heave" (which were not understood before the late 1970s), and also there are no LWIR data.[5] IR detectors at that time were of such low sensitivity that the concept of thermal (LWIR) detection of ballistic missiles was not considered feasible before the early 1970s.

"Heave" is a particular effect of a HANE-downward-traveling radiation (X-rays, UV radiation, charged particles) are absorbed in the 100-200 km atmospheric altitude range. This leads to local heating and the heated air parcels rise very rapidly (to ~10 km/sec). There exist limited, largely qualitative, data on Heave from past tests, but with no quantitatively adequate verification of the phenomenology, just as the LWIR signature of a HANE is not adequately measured or verified.[6] There is no doubt that heated air rises--e.g., the upper atmospheric density at a given altitude is higher at local noon than at local midnight, but the rise speed of heave following a nuclear explosion seems to be higher than is normally experienced in the non-nuclear-disturbed atmosphere. However, much of our understanding of heave is based on computer hydrodynamic analyses rather than on nuclear test data.

Note that there are no UV (< 300 nm) nuclear test data, and little analysis of UV effects.

---

5 Jack Carpenter states that "Liquid Helium cooled (4K) Gold-doped Germanium scanners and spectrographs were used in the 1958 Hardtack Test Series. The data were not handled well, so most were not useful. However, the reason LWIR experiments were not attempted on Fish Bowl (1962) was due to a lack of support by the Theoretical community. It was largely held that there was no infrared to be observed! ..."

CHART 8. THREE INDEPENDENT SETS OF UNCERTAINTIES:

- THREAT
- CODES
- BOMB OUTPUT

The architect, designer, or other user of environmental information--see Chart 2--needs this information to determine survivability or operability in the case of a specific nuclear threat. There are three independent sets of uncertainties, namely:

(1) in the threat postulated

(2) in the codes used to predict the actual ("free-field") environment.

(3) in the bomb output.

These are discussed next.

CHART 9. THREAT

THERE ARE DIFFERENT TYPES OF THREAT SCENARIOS MADE UP OUT OF DIFFERENT TACTICAL ELEMENTS:

- SALVAGE FUSING
- PRECURSORS
- ASAT BURSTS (PINS AND DANASAT)
- (IR AND RADAR) FENCES

  LADDER-UP AND LADDER-DOWN

  EMP

  ETC.

THESE ARE COMBINED INTO DIFFERENT THREAT TAPES WHICH ARE REPLACED OR UPDATED ON A REGULAR BASIS:

10/88	TSCB-1 (FROM BASELINE THREAT DOCUMENT)
2/89	EXCURSIONS: PO-1A, ETC
10/89	DTT-1

OTHERS WILL COME LATER

The threat is inherently variable--the system has to operate against a series of threats which change with time. We list different types of threat scenarios, and also indicate the canonical SDS threats which tend to change with time.

The different threat tactics are defined on p. 9, supplementing Chart 2.

CHART 10. UNCERTAINTIES IN HIGH-ALTITUDE NUCLEAR CODES

- DNA HAS SOME FIRST-PRINCIPLE PHENOMENOLOGY CODES. HOWEVER, THESE ARE MUCH TOO SLOW TO BE USED ON A REGULAR BASIS, IN PARTICULAR FOR MULTIBURST CASES.
- ACCORDINGLY, DNA HAS DEVELOPED TWO DIFFERENT PHYSICS-BASED ENGINEERING-LEVEL CODES DESIGNED TO COVER THE RANGE OF THREAT SCENARIOS.
    - NORSE (DEVELOPED BY PRI) AND SCENARIO (DEVELOPED BY MRC) ARE BOTH MULTIBURST CODES; WHICH SHOULD BE USED DEPENDS ON SPECIAL APPLICATION.
    - BOTH THESE CODES ARE BASED ON MUCH LONGER-RUNNING, PHYSICS-BASED, FIRST-PRINCIPLE CODES.
    - THE NORSE AND SCENARIO CODES HAVE DIFFERENT TREATMENTS FOR ENERGY DEPOSITION, CLOUD RISE, CHEMISTRY, AND HEAVE.
    - FIRST MASSIVE MULTIBURST RUN OF SCENARIO WAS IN 1986, INTERCOMPARISONS AND RECONCILIATIONS ARE ONGOING.
    - IT IS DIFFICULT TO PRESENT A GENERAL ESTIMATE OF RANGES OF UNCERTAINTY.
- FOR THREAT/ENGAGEMENT LEVEL APPLICATIONS IT IS NORMALLY NECESSARY TO USE FASTER BUT LESS PRECISE ENGAGEMENT-LEVEL CODES (*e.g.*, PEM, IRSIM. HISEMM, NWE.DAT, TREM) WHICH ARE BASED ON NORSE OR SCENARIO.

DNA's high-altitude phenomenology codes fall into three different levels of sophistication. There are first-principle codes (e.g., MICE/MELT, MICE/SALE) which attempt to account for all the important physics, but which require too much computer time to be run very frequently. There are physics-based engineering-level codes (NORSE and SCENARIO) which are also normally run on CRAY-class supercomputers, preferably by people who are familiar with the peculiarities of these codes and thus know how to interpret the results. These codes provide baseline information for use in much more rapidly-running codes (e.g., PEM, IRSim, HISEMM, NWE.DAT, etc., which are not always approved by DNA) employed in engagement modeling.

Note that while there are controllable decreases in precision as one goes from basic to engineering-level to engagement-level codes, yet one cannot exclude the possibility that some obscure piece of physics might have been omitted. Note also that some features are treated heuristically, rather than being modeled physically--for instance, the small-scale spatial structure giving rise to "clutter" or "scintillations" is treated heuristically in both NORSE and SCENARIO.

CHART 11. BASIC UNDERLYING UNCERTAINTIES IN BOMB OUTPUT

	UNCERTAINTY	IMPLICATIONS
YIELD	$\pm$ 25 %	SIZE OF DISTURBED REGION INTENSITY (& PERSISTENCE) OF DISTURBED BACKGROUNDS
RADIATION TEMPERATURE	$\pm$ 4X	AMOUNT OF ATMOSPHERIC HEAVE MWIR TRAPPING AND INTENSITY INTERMEDIATE ALTITUDE, SIZE AND KINEMATICS
FISSION FRACTION	$\pm$ 2X	BETA-PATCH EMISSION & DELAYED GAMMA FLUX

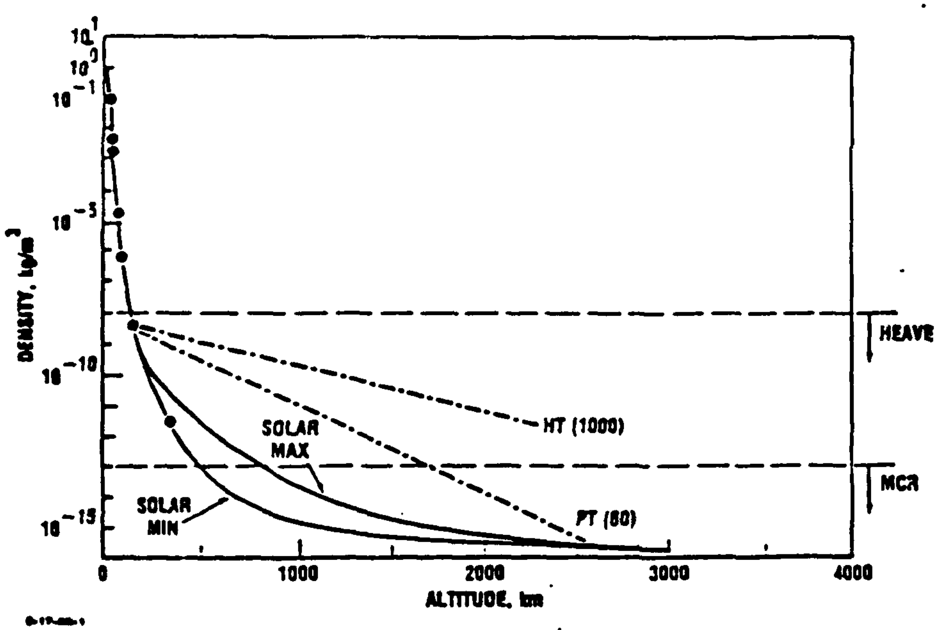
NOTE THAT EMISSION UNCERTAINTIES ARE NOT DIRECTLY RELATED TO UNDERLYING UNCERTAINTIES

This material is extracted from a briefing to POET in February 1989 by J. Carpenter, Visidyne, Inc. (see also Wells and Leeper, 1989) who makes the following descriptive comments:

> There are basic underlying uncertainties in our *a priori* knowledge of nuclear devices used by potential opponents. This page (Chart 11) gives our estimates in three critical areas, namely, the total yield of the device, the X-ray radiating temperature, and the fraction of the yield that is due to the fission (as opposed to the fusion) energy release. The first obviously affects the size of the disturbed region and the intensity and persistence of the disturbed backgrounds (UV, visible, and IR). This directly influences the amount of the lower atmosphere heaved up to higher altitudes and for High Altitude or Exoatmospheric shots, the CO_2 radiation trapping and the consequent MWIR intensity. For Intermediate Altitude shots, the radiation spectrum determines the initial size of the fireball and its radiation and kinematical histories. The last, the fission fraction, determines the intensity of the beta patch emissions and, of course, the delayed gamma flux on detectors in the vicinity.
>
> (J. Carpenter , Appendix F in Wells and Leeper, 1989).

CHART 12. NORMAL AND HEAVED ATMOSPHERIC DENSITY AS FUNCTION OF ALTITUDE

WE SHOW THE AMBIENT DENSITY CORRESPONDING TO LOW AND HIGH SOLAR ACTIVITY, AND THE PERTURBED DENSITY P (60) ALONG THE PLUME CORRESPONDING TO 60 - 1 Mt BURSTS, AND THE GENERAL HEAVE H (1000) DUE TO 1000 - 1 MT BURSTS (FROM SCENARIO SIMULATION MS 1.1). TEST DATA ARE INDICATED. NUMBER DENSITY FIGURES ARE ALSO SHOWN.



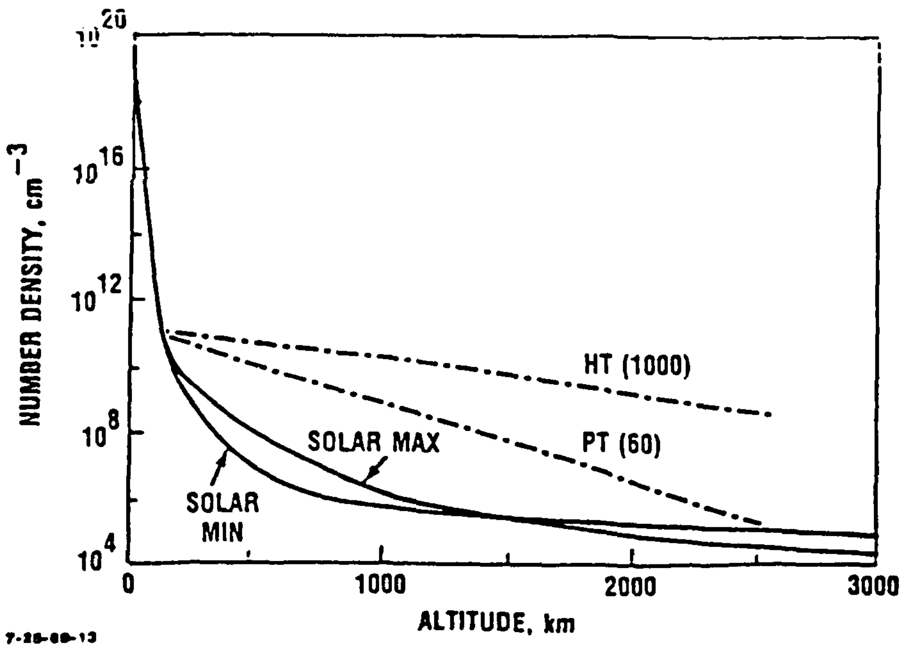


Chart 12 discusses "Atmospheric Heave," the rapid buoyant rise of the atmosphere above 100-200 km (at speeds of order 10 km/sec) resulting from the absorption of bomb energy in the 100-200 km altitude range. We show :

- Ambient atmospheric density as function of altitude corresponding to low and high solar activity.
- Altitude of high-altitude atmospheric bursts for which there are substantial data.
- Effective density plots PT(60) and HT(1000) corresponding to the heaved atmosphere (~10-30 sec) after the detonation of 60 and 1000 high-altitude megaton-yield bursts as predicted by the computer simulation MS-1.1 (White et al., 1987a[6,7]).
- Data for both mass density (kg/m^3) and number density (cm^3).[8]
- "Heave" is important for densities below approximately 10^{-8} kg/m^3. At densities below 10^{-13} kg/m^3 (where there are no nuclear test data) the phenomenology may be rather different, characterized as "magnetic confinement regime" (or MCR), with geomagnetic field effects dominating over air mass density effects.[9]
- Note that the number density above about 100 km remains in the range 10^{10}-10^{11} atoms/cm^3. Because it is difficult to ionize air atoms or molecules more than singly, this suggests that (at times greater than 30-60 sec after a burst) the peak ionization will not be greater than 10^{10}-10^{11} electrons/cm^3. Some implications of this are discussed below--see discussion following Chart 13.

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6 Some of these calculations have been repeated since 1987, and the electron and neutral densities are now found to be smaller by a factor of 2-3.

7 T stands for total air density; P denotes "plume"--as in the case of the 60-burst scenario only a plume of horizontal extent ~ 200 km is heaved to this extent, while for the 1000-burst scenario the whole atmosphere of horizontal extent ~ 2000 km is heaved substantially--hence the term HT(1000) versus PT(60). Appendix B indicates how lines HT(1000) and PT(60) were obtained from a computer simulation.

8 The reason why the number density curves for "SOLAR MAXIMUM" and "SOLAR MINIMUM" curves cross with altitude while the mass density curves do not cross is that the temperature and effective atomic weight vary differently with altitude in these two cases.

9 Note that multiple high-altitude nuclear explosions create large plasma bubbles which perturb the geomagnetic field. This effect has not been modeled thus far.

CHART 13. ENHANCED IONIZATION DUE TO SINGLE AND MULTIPLE NUCLEAR EXPLOSIONS AS FUNCTIONS OF ALTITUDE

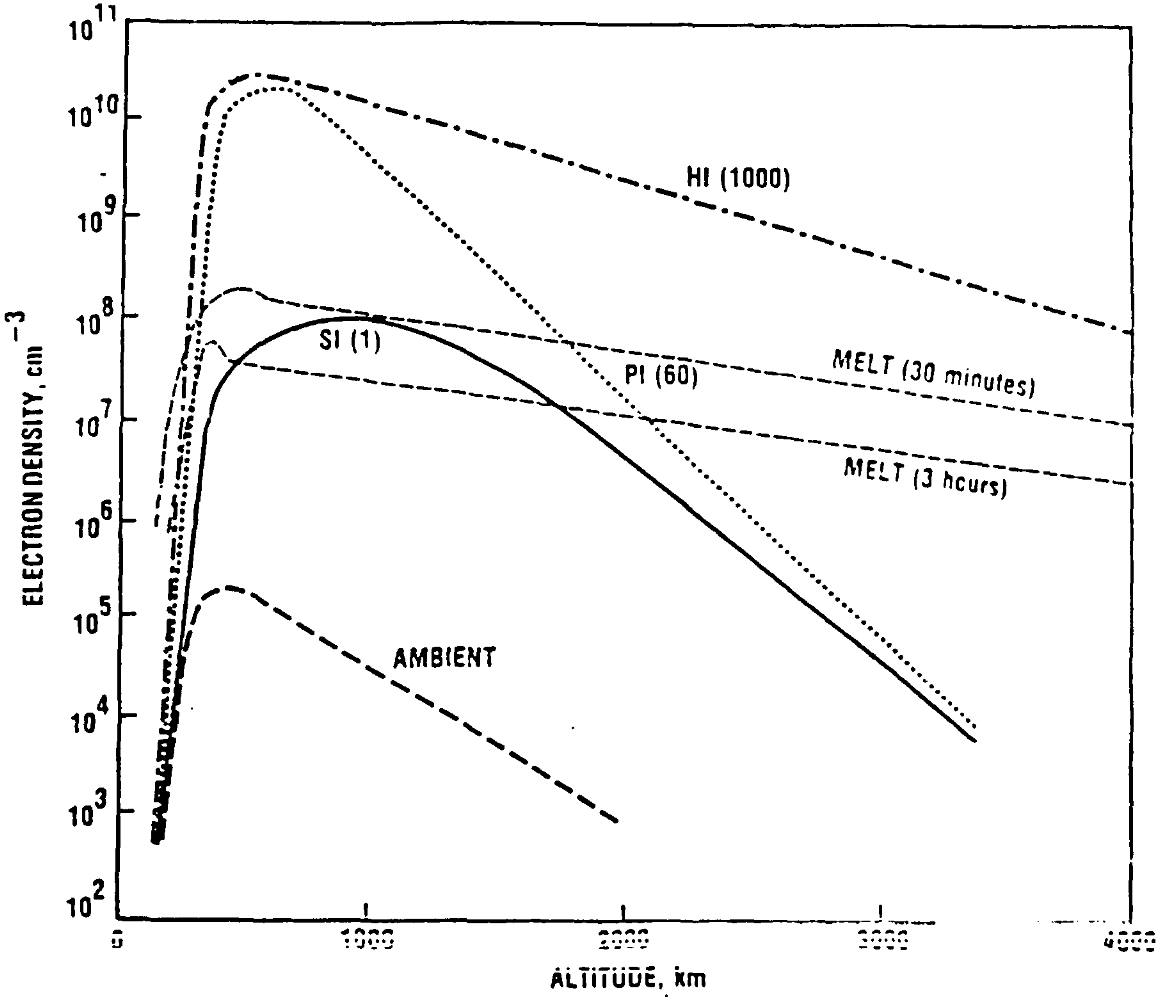

Chart 13 shows the ambient ionosphere, the ionization 5 minutes after a single 1 Mt detonation at 150 km (Hain et al., 1985), which is labeled SI(1), and the ionization after the 60 and 1000 detonations of SCENARIO run MS-1.1, which are labeled PI(60) and HI(1000) in Chart 13 as compared with the neutral densities PT(90) and HT(1000) of Chart 12. We also show the results of a single burst MELT code run (from White et al., 1987b)--1 Mt at 200 km--at 30 minutes and 3 hours after the burst, which should be compared with the single-burst curve SI(1), both to indicate possible variabilities of different predictions and to remind the reader that the enhanced high-altitude ionization disappears very slowly.

Because it takes a great deal of energy to bring air above an ionization of approximately one electron per air atom, the phenomenology computer codes suggest that the ionization environment saturates, i.e., beyond some number density of nuclear bursts the effective ionization at times greater than 30-60 sec after burst does not increase significantly if heave is folded into the computation. From Chart 12 we see that the total number density of the heaved atmosphere above ~200 km is no greater than 10^{11} particles/cm^3. Thus one sees that it is very difficult to get an ionization in excess of 10^{11} electrons/cm^3. This has strong implications for the propagation of electromagnetic waves through the ionized medium.[10]

This figure is meant to show the following:

(a) Even a single high-yield nuclear explosion produces a dramatic enhancement in the atmospheric ionization.

(b) This enhancement lasts for quite a long time.

(c) The total ionization due to multiple high-altitude bursts shows saturation.

(d) Do not take numerical details of the prediction too seriously.

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10 Fluctuations in electron density are also important, and must be modeled appropriately.

CHART 14. THE BOTTOM LINE--DATA:

- VULNERABILITY - LOTS OF DATA (AND CAPABILITY TO GET MORE FROM UGT/AGT'S)

- LOW-ALTITUDE BURSTS (< 30 km):
  - CONFINED FIREBALLS
  - LOTS OF DATA IN VISIBLE AND NEAR-IR
- INTERMEDIATE-ALTITUDE BURSTS (30-90 km):
  - LARGELY CONFINED FIREBALLS
  - *SOME OPTICAL AND RF DATA*
  - COMPLEX CHEMISTRY
  - EXTENSIVE ANALYSIS

- HIGH ALTITUDE BURSTS: VERY LIMITED DATA BASE ON OPTICAL AND RF PHENOMENOLOGY
  - LARGE GEOMETRIC EXTENT, I.e., MULTIBURST EFFECTS IMPORTANT
  - NO QUANTITATIVE DATA ON HEAVE
  - NO IR DATA BEYOND 5.5 μm
  - NO MULTIBURST DATA
  - LIMITED UV DATA

Chart 14 summarizes the data we have available and also where we do not have data.

CHART 15. THE BOTTOM LINE--MODELS:

- HIGH ALTITUDE ELECTROMAGNETIC PROPAGATION EFFECTS DEPEND ON:
    - ELECTRON DENSITY (WHICH IS DRIVEN BY HEAVE AND SATURATES)
    - SPATIAL AND TEMPORAL STRUCTURE IS CRUCIAL
    - GEOMETRIC EXTENT OF DISTURBED REGION

- HIGH ALTITUDE "REDOUT" IS SUM OF
    - PLASMA RADIATION, WHICH DEPENDS MAINLY ON SAME PARAMETERS AS EM PROPAGATION.
    - MOLECULAR RADIATION:
        - HOW HIGH UP ARE THERE RADIATING MOLECULES?
        - KINETICS AND EFFECTIVE RADIATING TEMPERATURE

- UV: - VERY LIMITED DATA: MORE ANALYSIS MAY BE APPROPRIATE

- DETAILS OF BOTH HEAVE AND STRUCTURE MAY BE VERY IMPORTANT QUANTITATIVELY

Chart 15 points out the physical effects that affect both the electromagnetic wave propagation, where our understanding is relatively adequate, and also the high-altitude IR background or "Redout," which is subject to considerably larger uncertainties--because there are no direct test data available. The IR signature is due in part to plasma radiation, which is affected by the same factors as is electromagnetic wave propagation, and in part to molecular radiation which is subject to different factors, such as how high up are there radiating molecules? This is a function of <u>Heave</u> which brings up radiating molecules like CO_2 from below 100 km, and also of the heating of air parcels which produces NO (and NO_2). The radiation from these molecules depends on their concentration and effective radiation temperature. Note that while we seem to have a fair understanding of the saturation in ionization, yet there is less experience with molecular radiation, so that we do not yet have a comparable understanding of saturation in IR radiation. This chart also reminds you of the limited understanding of UV radiation from nuclear fireballs.

Note also that the DNA community uses the Wittwer-Kilb model--Wittwer and Kilb, 1986--as their single approved structure model.

CHART 16. CLOSING COMMENTS

- THE NUCLEAR-DISTURBED UPPER ATMOSPHERE CAN BE QUITE DIFFERENT FROM THE AMBIENT ATMOSPHERE

- THERE ARE LARGE UNCERTAINTIES OR VARIABILITIES IN THE THREAT

- THERE ARE SIGNIFICANT UNCERTAINTIES IN THE PHENOMENA AND THE CODES:

  -- RECOGNIZE THE VERY LIMITED HIGH-ALTITUDE DATA BASE

  -- REFER TO DNA OR THEIR CONTRACTORS FOR SPECIFIC APPLICATIONS

Note that the present discussion is largely qualitative because it is impossible to give quantitative estimates that are both generally applicable and non-trivial.

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11 This is a revision of the Second Edition of 1962; there is a new Third Edition of 1977, but while it gives a more up-to-date description of the models, this is not as good as the Second Edition as far as describing the observed phenomena is concerned.

12 This is Volume 1 of a 7-Volume set which reviews the accepted state of the art of summer 1986.

APPENDIX A

DIFFERENT WAYS TO CHARACTERIZE THE NUCLEAR ENVIRONMENT

BY ALTITUDE

- Terrestrial near surface
- Lower Atmosphere, < 30 km
- Upper Atmosphere, 30-1500 km
- Exoatmosphere, > 1500 km

BY STATISTIC

- Nominal/expected
- Fluctuation
- Random
- Bounding

BY PHENOMENOLOGY

- Air density (including atmospheric heave)
- Electron density
- Mass velocity
- Electron temperature
- Gas temperature
- Spatial temperature structure

BY PERSISTENCE OF EFFECT

- Prompt (Blast, X-ray)
- Persistent (Heave, *Excess Electron Density*, *Radiation*, *Irradiance*)

BY TYPE:

IR EFFECTS

- Total nominal radiance for particular band
- Nominal sensor-aimpoint transmission for particular band
- Nominal power spatial structure for particular band

RF EFFECTS

- One-way attenuation & refraction
- Scintillation/Clutter

EMP

BLAST EFFECTS

- Overdensity
- Overpressure
- Dynamic pressure
- Air velocity

PROMPT RADIATION

- Neutron fluence
- Gamma fluence
- Peak gamma flux
- X-ray fluence

DELAYED RADIATION

- Sustained neutron
- Sustained gamma
- Sustained thermal
- Sustained beta

GROUND MOTION

APPENDIX B

RESULTS FROM THE SCENARIO COMPUTATION FOR MASSIVE MULTIBURST CASE MS-1.1 (WHITE et al., 1987A*)

Fig. B.1. Total Mass Density at t = 1 minute (after 60 bursts) and at t = 16.7 min. (after 1000 bursts).

Fig. B.2. Total Ionization (Electron Number Density) at t = 1 minute (60 bursts) and 16.7 minutes (1000 bursts)

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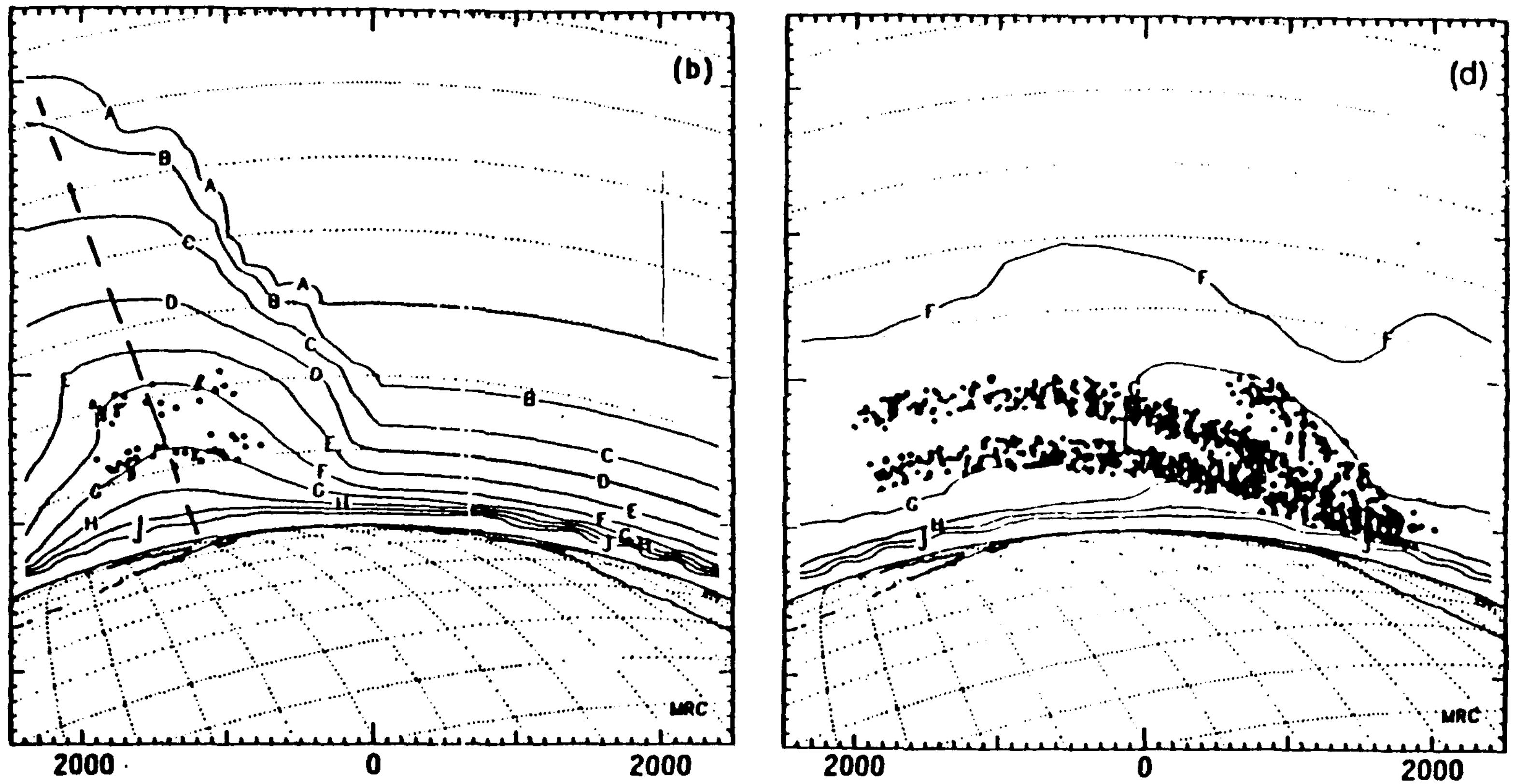
* Since these computations were done, there have been changes in the SCENARIO code which reduce the total density and ionization by up to a factor 2-3. The difference is not significant within the total accuracy of the calculations.

FIGURE B.1. TOTAL MASS DENSITY AT T = 1 MINUTE (AFTER 60 BURSTS) AND AT T = 16.7 MINUTES (AFTER 1000 BURSTS)



Contour Values (gm/cm³):

A = 10^{-18} B = 10^{-17} C = 10^{-16} D = 10^{-15} E = 10^{-14}
F = 10^{-13} G = 10^{-12} H = 10^{-11} I = 10^{-10} J = 10^{-9}

Contour Values (gm/cm³):

A = 10^{-18} B = 10^{-17} C = 10^{-16} D = 10^{-15} E = 10^{-14}
F = 10^{-13} G = 10^{-12} H = 10^{-11} I = 10^{-10} J = 10^{-9}

FIGURE B.2. TOTAL IONIZATION (ELECTRON NUMBER DENSITY) AT T = 1 MINUTE (60 BURSTS) AND 16.7 MINUTES (1000 BURSTS)